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ANALYSIS TECHNIQUES FOR AIRBORNE LASER RANGE SAFETY EVALUATIONS

BY M.S. RAMSBURG   D. L. JENKINS   R. D. DOERFLEIN

COMBAT SYSTEMS DEPARTMENT

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Techniques to evaluate safety of airborne laser operations on the range are reported. The objectives of the safety evaluations were to (a) protect civilian and military personnel from the hazards associated with lasers, (b) provide users with the least restrictive constraints in which to perform their mission and still maintain an adequate degree of safety, and (c) develop a data base for the Navy in the event of suspected laser exposure or other related incidents involving military or civilian personnel.

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A microcomputer code, written in ANSI 77 FORTRAN, has been developed, which will provide safe flight profiles for airborne laser systems. The output of this code can also be used in establishing operating areas for ground-based lasers. Input to the code includes output parameters, NOHD and assigned buffer zone for the laser system, as well as parameters describing the geometry of the range.

FOREWORD

The Naval Surface Weapons Center was tasked as the Navy's Technical Direction Agent for laser safety in 1979 and has been providing technical assistance to Navy and Marine Corps range personnel and system users in the area of laser safety. In order to properly assist these personnel, techniques have been developed to perform safety evaluations of laser operations on the ranges. This report discusses the techniques used to perform these evaluations.

The assistance provided by H. L. Simpson of the Electro-Optics Branch (Code N54) in the development of these techniques is gratefully acknowleged.

This report has been reviewed and approved by J. F. Horton, Head, Systems Safety Division.

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Combat Systems Department

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EXECUTIVE SUMMARY

A program is currently under way at the Naval Surface Weapons Center (NSWC) to evaluate the safety of laser rangefinder/designator operations on Navy and Marine Corps range facilities. The principle laser hazard of concern is the retinal damage that can be caused by direct viewing of the laser beam or its specular (mirror-like) reflection. Light from lasers currently being used on Navy and Marine Corps ranges (visible and near infrared) is focused by the eye, making the retina on the order of 100,000 times more sensitive to damage than the remainder of the body.

Range safety evaluation techniques have been developed that provide maximum operational capability, while assuring the safety of military and civilian personnel. Equations have been derived for determining the minimum laser altitude at any given range to the target which will maintain the laser beam, and its associated safety buffer zone, within property and airspace owned and/or controlled by the government. These techniques have been applied to numerous Navy and Marine Corps ranges worldwide.

A microcomputer code, written in ANSI 77 FORTRAN, has been developed, which will provide safe flight profiles for airborne laser systems. The output of this code can also be used to establish operating areas for ground-based laser systems.

INTRODUCTION

BACKGROUND

Prior to 1979, there was no coordinated effort within the Navy for laser safety, and each command was responsible for implementing a laser safety program. This approach placed the burden of responsibility on personnel who did not possess the background to institute a comprehensive laser safety program. This lack of coordination resulted in large variations in the laser safety programs at the different installations, with some being overly restrictive, while others were less than optimum.

In order to overcome these difficulties, the Chief of Naval Material designated the Naval Electronic Systems Command (NAVELEX) as the lead agency for laser safety within the Naval Material Command (Reference 1). This responsibility was given to the NAVELEX Safety Office (ELEX-01K), who tasked the Naval Surface Weapons Center to serve as the Navy's Technical Direction Agent (TDA) for laser safety. As part of its TDA responsibilities, NSWC was requested to conduct laser safety surveys of Navy and Marine Corps ranges to provide technical assistance and guidance in the safe use of laser systems.

In order to perform consistent range surveys, a comprehensive plan was developed to provide maximum operational capabilities while ensuring safe use of laser systems. The first step in establishing the survey plan was to formulate the criteria by which the surveys would be performed. The basic objectives were as follows:

a. Protect both civilian and military personnel from the hazards associated with lasers

b. Provide users with the least restrictive constraints in which to perform their mission and still maintain an adequate degree of safety

c. Develop a data base for the Navy in the event of suspected laser exposure or other related incidents involving military or civilian personnel

CURRENT PROGRAM

A program is now under way to evaluate the safety of laser operations on Navy and Marine Corps facilities. Training of operational forces includes active laser illumination (rangefinding or illumination for laser-guided ordnance) of shore and at-sea targets.

Range operations, procedures, and safety regulations are being revised to reflect laser range safety requirements suitable to the needs of the ranges and at-sea training exercises. Shore targets are normally located within specified restricted areas within well-defined boundaries. Constraints for at-sea towed targets are primarily related to the fixed relationship between the target and the towing ship.

The principal laser hazard of concern is the retinal damage that can be caused by direct viewing of the laser beam or its specular reflection. Personnel required to be in a laser hazard area must wear eye protection. However, to protect personnel outside of controlled and restricted areas, the laser beam and its specular reflection must be contained inside the boundaries of such areas. This can be accomplished by establishing constraints (i.e., flight profiles for airborne lasers or specified operating areas for shipboard and ground lasers) that assure the containment of the laser beam within specified boundaries of the range/target areas. A related consideration is the requirement that any hazards due to the laser beam or its specular reflection will terminate within a prescribed restricted airspace. The methods described herein have been developed by NSWC and used successfully to perform laser safety evaluations of Navy and Marine Corps ranges worldwide. Although the basic equations were derived for airborne laser systems, they are equally applicable to ground-based lasers.

The equations derived lead to a direct solution for laser altitude above mean sea level (MSL), which will satisfy the safety constraints of a particular range and at a specified distance from the target. If specular reflections from water are present in the target area, the complexity of the problem is increased significantly. A computer code using an iterative solution is employed.

Required input parameters include the measured output parameters and nominal ocular hazard distance (NOHD) of the laser system(s) to be used on the range and the safety buffer zone assigned to the system(s). Data collected during a site survey of the range facility (i.e., topological maps, target locations, range operating procedures, numbers and locations of specular reflectors on the range, restricted ground space and airspace, etc.) are also required.

The need for actual field measurement of laser system parameters should be accentuated. Atmospheric effects, such as scintillation and scattering, will cause the laser system parameters as measured in the far field to vary significantly from the same parameters as measured in the laboratory on the same laser system. As an example, the effective beam divergence of a laser system as measured in a field environment may be a factor of two to three smaller than as measured in the laboratory. This would cause the NOHD for the system to be on the order of two or three times longer than would be expected from laboratory data.

SCOPE

This report addresses the analytical and mathematical techniques used to prepare safe flight profiles for airborne laser systems to assure that laser beams and associated safety zones fall within the prescribed boundaries of controlled and restricted ground space and airspace. The equations and analytical approach have been applied to ground laser systems and are directly applicable to shipboard lasers.

APPROACH

OBJECTIVE

The objective of performing laser safety evaluations of Navy and Marine Corps ranges is to assure that no unprotected personnel are exposed to laser radiation above the protection standards specified in Reference 2 without placing unnecessary restrictions on laser system utilization. In order to meet this objective, every reasonable and prudent precaution must be taken to terminate the laser beam and its associated buffer zone on property or airspace owned and/or controlled by the government. This is accomplished by either using a backstop (i.e., vegetation, berms, terrain, etc.) or terminating the hazard at the NOHD of the system.

On most ranges some personnel are required to be on the range during laser operations for instrumentation operations, fall of shot spotting, and other required activities. The locations of all occupied areas must be determined and evaluated relative to the laser hazard area. The type of laser protective devices required, if any, must then be determined for each manned location.

Other items considered during the evaluation include: extent of range boundaries, required warning signs, number and locations of any specular reflectors, ease of public access to the range, airspace restrictions and local operating procedures. Any conditions peculiar to the specific range, such as cattle grazing rights or endangered wildlife, must be considered.

NOMINAL OCULAR HAZARD DISTANCE

The part of the body which is most sensitive to damage from the types of lasers currently in use on Navy ranges (visible and near infrared lasers) is the eye. This hazard is best illustrated by referring to Figure 1. The light from a conventional light source is focused by the eye to form an extended image on the retina, whereas laser light is focused to a very small spot (on the order of 2 to 10 micrometers (μm)).

This focusing effect causes the eye to be much more sensitive to laser radiation than other body parts. When viewing a point source of light such as a laser or a distant star, the retinal irradiance is greatly amplified over the corneal irradiance. That is, the "optical gain" of the eye (the ratio of the corneal-to-retinal irradiance) is approximately 100,000 times (Reference 3).

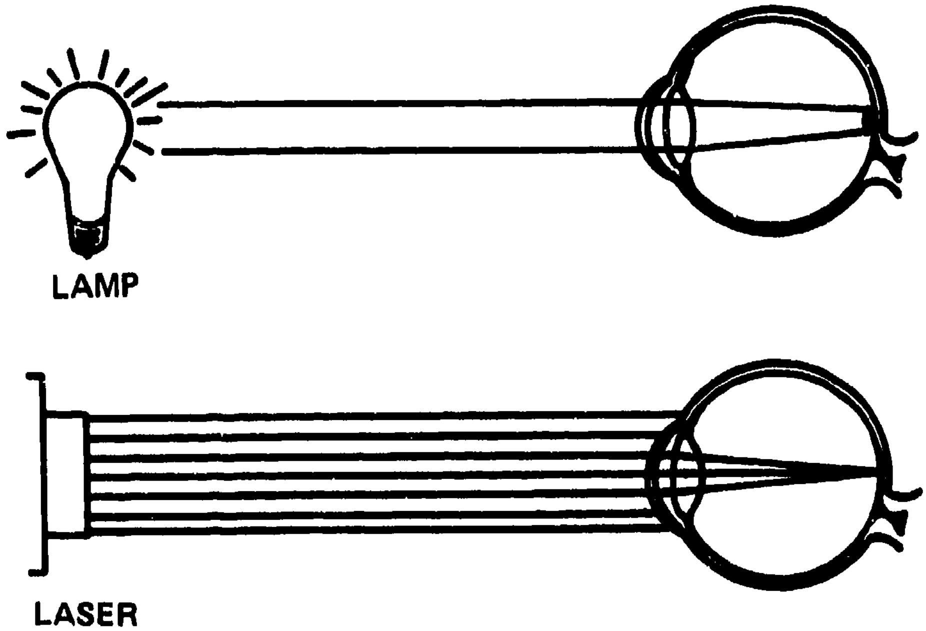

Figure 1. Focusing of a LASER Beam and Conventional Light Source by the Eye

Since the output of a laser is monochromatic and all waves are in phase, the wave produced can be expressed as a simple spherical wave with a radius r. Figure 2 illustrates this principle.

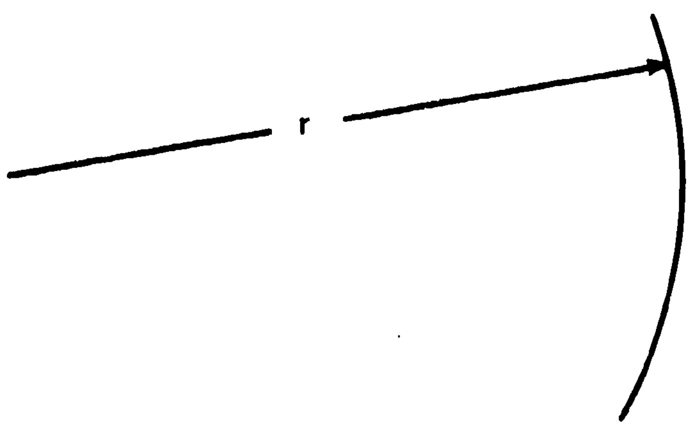

Figure 2. A Simple Spherical Wavefront of Radius r

If one would measure the energy level of small sections of the cross section of the laser beam for most currently fielded military lasers, one would see a Gaussian energy distribution (Figure 3). Of interest to laser safety hazard analysis is what fraction of the total energy available will pass through various aperture sizes (i.e., 8-cm entrance aperture optics). One approximation is the range equation based on a rectangular beam profile as used in ANSI and other documents. A more accurate formula is that developed by Marshall (Reference 4) and appears as follows:

$$H = 2.6\, Q\,(1 - e^{-D_o^2/D_L^2})$$

where

D_L = Diameter of the laser beams at the 1/e points
D_o = Diameter of the measuring or collecting aperture
Q = Total available energy out of the laser
H = Radiant energy

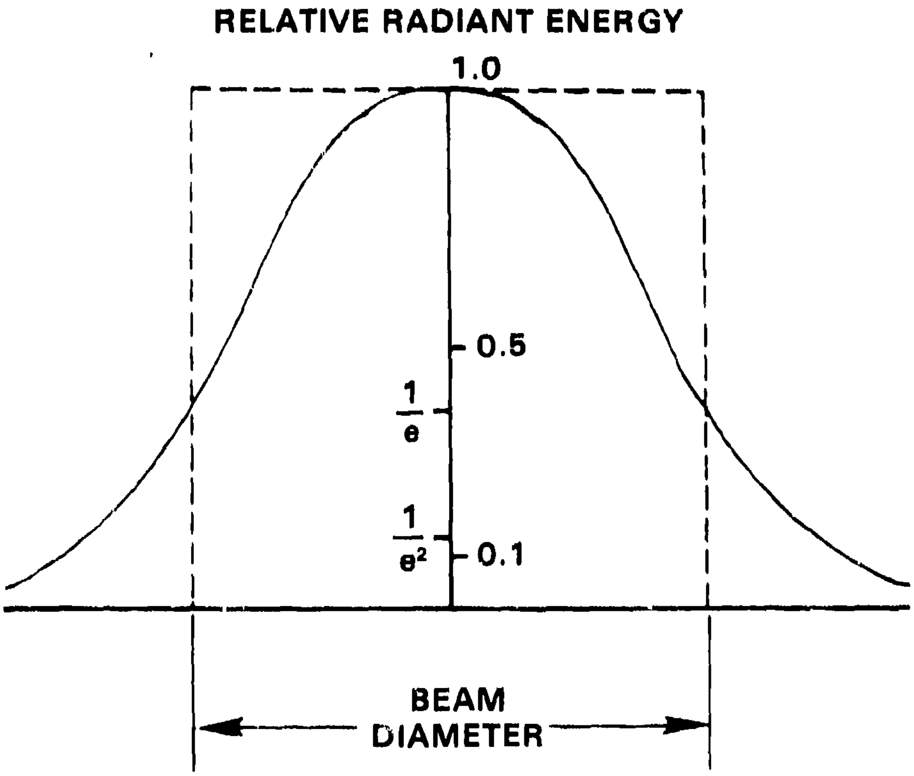

Figure 3. A Gaussian-Shaped Laser Beam Profile

When predicting radiant energy values at some point downrange from the laser, the beam diameter will be a function of the output beam diameter and the amount of divergence the beam will have (Figure 4). Consequently, for small-beam divergences, the beam diameter can be calculated by

$$D_L = a + R\phi \tag{2}$$

where

a = exit beam diameter expressed in cm at the 1/e points
ϕ = beam divergence as expressed in radians
R = distance from the laser in cm

Equation 1 now becomes:

$$H = 2.6\ Q\ (1 - e^{-D_o^2/(a + R\phi)^2}) \tag{3}$$

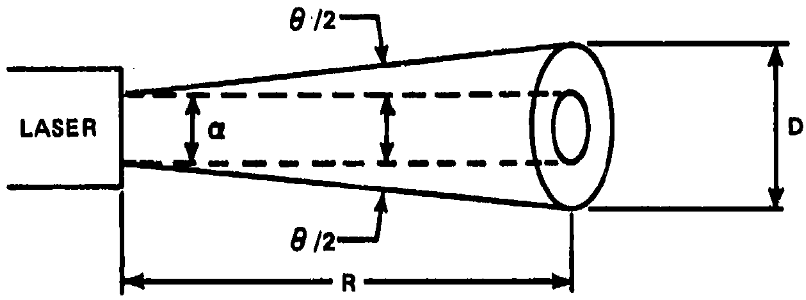

Figure 4. Beam Divergence

This equation is really only valid for small distances downrange. The atmosphere then plays an important role in attenuating or reducing the available energy through absorption and scattering. One could use Equation 3, with the knowledge that this equation will predict radiant energy values much higher than real-life values. The distances required to reduce the radiant energy to levels below the protection standards would be quite long and could be much too restrictive for a given range. The best approach is to obtain the amount of reduction of the radiant energy that a given atmosphere would provide. The amount of energy available at a given distance from the laser is given by

$$Q(r) = Q(o)\ e^{-\mu R} \tag{4}$$

where

μ = atmospheric attenuation in cm^{-1}
R = distance from the laser in cm

Equation 3 now becomes

$$H = 2.6\ Q\ (1 - e^{-D_o^2/(a + R\phi)^2})\ e^{-\mu R} \quad (5)$$

The nominal ocular hazard distance (NOHD) is that distance downrange from the laser where the radiant energy incident to the cornea of an unprotected person would be below current protection standards. To determine this range, one substitutes into H of Equation 5 the protection standard as determined by ANSI and then solves for R. This calculation would appear as

$$R = \frac{1}{\phi} \left\{ \sqrt{\frac{-D_o^2}{\mathrm{Ln}\ \left(1 - \frac{H}{2.6\ Q\ e^{-\mu R}}\right)}} - a \right\} \quad (6)$$

Solution of Equation 6 requires an iterative technique ideally suited for programmable calculators or computers.

The NOHDs of several laser systems that could be used on Navy and Marine Corps ranges are listed in Appendix A.

SAFETY BUFFER ZONE

Before performing a range safety analysis, a safety buffer zone must be established for each laser system to be used on the range. This buffer zone is a conical volume centered on the laser's line of sight with its apex at the aperture of the laser (see Figure 5) in which the beam will be contained with a high degree of certainty. The size of the buffer zone is typically set, as a minimum, to five times the demonstrated pointing accuracy of the system. To facilitate uniformity of application and to avoid confusion when multiple laser systems are used on the various ranges, standard buffer zones of 2, 5, 10, and 15 mrad (half angle) have been informally established.

The factors evaluated to determine this zone include the boresight retention capability of the system, tracking accuracy, and the operator's ability to accurately track the target. This evaluation is generally performed concurrently with the measurements to determine the NOHD of the system.

The buffer zones applies to several laser systems, which may be used on Navy and Marine Corps ranges, are listed in Appendix A.

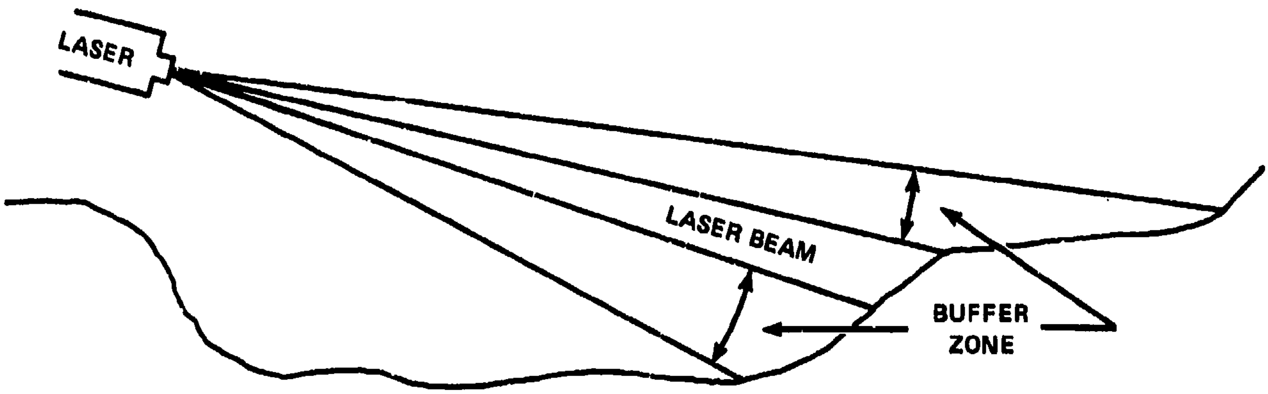

Figure 5. Example of the Use of a Buffer Zone

SURVEY

Prior to performing a laser safety evaluation, a site survey of the proposed laser range must be performed to:

a. Collect appropriate input information for the evaluation

b. Evaluate the physical condition of the targets and target areas to determine what types of specular reflection hazards, if any, are present

c. Assure that no hazards exist on the range which would not be recognized as such by personnel who are untrained in laser safety

The various items evaluated during the site survey are discussed below.

RANGE FACILITIES

The range facilities are evaluated in terms of location relative to populated areas, military and civilian industrial sites, and water surface traffic. The methods used to control access to the potential laser hazard area (i.e., fences, warning signs, airspace restrictions, water surface danger areas, etc.) must be evaluated for adequacy. The locations of all occupied areas on the range, such as control towers, must be determined, as well as the habitat of any endangered wildlife in the range area.

Locations of target areas and high-explosive-impact areas are determined. Target areas are evaluated for types of targets currently in position. Vehicular targets, in particular, could have chrome bumpers, windshields, or other flat glass or chrome surfaces. Presence of these types of surfaces could generate a specular reflection when optical radiation is incident to the target. This hazard could even exist if the surface were bent or broken due to previous ordnance impact or explosion. Broken or bent specular surfaces could still have an adequately large flat surface remaining to generate a specular reflection. Unexploded ordnance areas in or surrounding the proposed target area could have an impact on the advisability of policing or masking existing specular surfaces.

Terrain features on and surrounding the range are evaluated for impact on laser safety. Usable terrain and vegetation backstops are identified and located on maps of the range area. Any mountain peaks outside the range are examined to verify that such obstructions as radio or television towers or park service observation towers do not extend into the laser buffer zone between the laser and the target. This consideration should only effect airborne laser systems when active target illumination commences before the aircraft enters the range boundaries.

TARGET/TARGET AREA CONDITION

Careful attention must be paid to the condition of the target and surrounding laser hazard area. Any specular reflectors on or around the laser targets must be either removed or rendered diffuse. Specular reflectors may be rendered diffuse by painting with a flat (non-specularly reflecting) paint. Merely covering a specular reflector is not adequate, since the covering material is usually susceptible to damage by ordnance. The position and orientation of any specular reflectors, which cannot be removed or rendered diffuse must be noted so that they can be considered during the laser safety evaluation.

Standing water (i.e., lakes, ponds, lagoons, marshes, etc.) in the potential laser hazard area must be noted so they may be considered during the laser safety evaluation. The possibility and locations of seasonal standing water, such as puddles after rainfall or wet weather marshes, must be determined during discussions with range personnel.

Standing water does not usually make a range area unusable since the reflected beam is directed upward into controlled airspace. Some ranges, however, do not have adequate restricted airspace to terminate the hazard. In those cases, requirements must be generated to prevent laser operations if standing water is present on the range.

RANGE OPERATIONS

General range operating and safety requirements are the responsibility of the Commanding Officer and are generally promulgated by way of local instructions. These instructions are reviewed to determine which existing requirements impact the safety of laser operations on the range and recommended additions, if any. Existing operational safety requirements impacting the laser safety evaluation would include:

a. Limitations on allowable run-in headings (airborne lasers only)

b. Minimum flight altitudes (airborne lasers only)

c. Airspace surveillance

d. Flyover requirements to assure range security

e. Locations of control towers and other manned areas

SYSTEM PERFORMANCE

In order to meet mission requirements, the stability, pointing accuracy and boresight retention capabilities of a laser rangefinder/designator system must exceed those required for range safety. In establishing the laser safety buffer zone for a particular system, a factor of at least five times the demonstrated accuracy of the system is used. This factor has been used to compensate for such factors as untrained operators, adverse environmental factors, and use of the system at the limits of its capability.

If multiple laser systems with similar capabilities are to be used on the same range, only the worst-case parameters are used in the laser safety evaluation of the range. As an example, the A-6E Target Recognition Attack Multisensor (TRAM), the OV-10D Night Observation System (NOS) and the F-111 Pave Tack systems have similar performance capabilities and may be used in the same range facility. The NOHDs of the systems, as measured in the far field, are 8.1 nmi, 6.1 nmi, and 8.6 nmi, respectively (References 5, 6, and 7). All three systems have been assigned a safety buffer zone of 5 mrad. A range safety evaluation based on an NOHD of 8.6 nmi and a 5-mrad buffer zone would, therefore, allow safe use of all three systems on the range without the confusion of three different sets of restrictions. The system parameters are also adequately similar that the least hazardous system is not unduly restricted.

CALCULATIONS

The equations derived herein lead to a direct solution for the minimum laser altitude above MSL, which will satisfy the safety constraints for use of an airborne laser system on a particular range and at a specified distance from the target. Although derived for airborne laser systems, the equations are equally applicable to ground-based lasers.

The use of these equations in the case of shipboard laser systems would provide pessimistic results. The lack of terrain features to act as a backstop in an open ocean environment, when combined with the longer NOHD of a more powerful shipboard laser system, causes the curvature of the earth to play a significant role in shipboard laser evaluations. The optical horizon from an elevation of 80-ft MSL is approximately 9.5 nmi. Since at a range of 19 nmi (the approximate NOHD for unaided viewing of some proposed shipboard laser systems), the propagated beam could not possibly be below 80-ft MSL, the use of optical aides aboard other surface vessels would not increase the probability of exposure. It would, however, increase the extent of damage should an exposure occur.

DERIVATION OF EQUATIONS

Buffered Footprint Definition

The buffered footprint is the projection of the laser beam and its associated buffer zone on the ground surrounding the intended target. The footprint configuration and size are determined by the range from the laser aperture to the target, the incident angle of the laser beam line of sight on the target or range area plane and the assigned buffer.

Figure 6 illustrates the geometry of the buffered footprint. The footprint is an ellipse whose width is typically quite small and a simple function of the distance to the target. The spreading of the beam along the ground in the direction of the laser line of sight is of primary concern and changes drastically as a function of the aircraft's height above and distance to the target.

Without Specular Reflections

Provided that the laser target and surrounding area are clear of specular reflectors, the mathematical model used to evaluate range safety must assure that the laser beam and its associated buffered footprint fall within the prescribed boundaries of the controlled and restricted ground space. The following paragraphs describe the derivation of the equations used for this model.

The problem can be broken into two constraints, the first being that the buffered footprint does not exceed the available controlled area between the target and the laser (near buffer). Likewise, the second constraint is that the buffered footprint does not exceed the available controlled area beyond the target (far buffer).

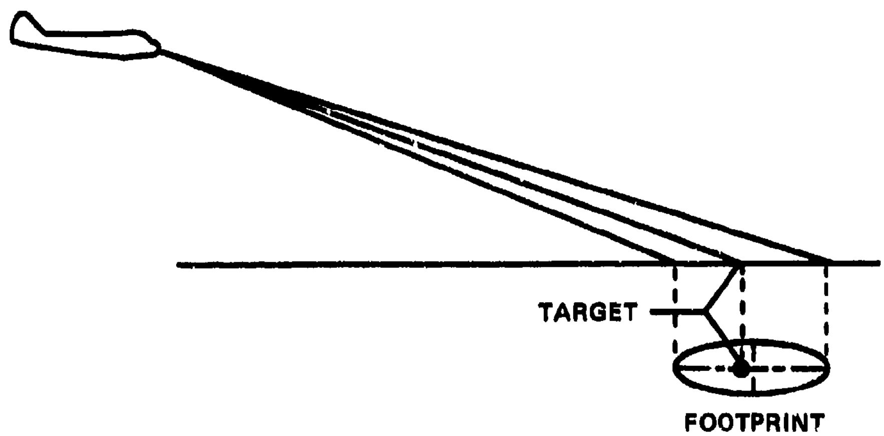

Figure 6. Laser Footprint

Addressing the near boundary constraint first, Figure 7 illustrates the geometry of the problem. In Figure 7, LA is the laser altitude above the target; NA is the near range boundary elevation above the target; RL is the laser to near boundary range; RN is the near boundary to target range; α is the angle formed by the line from the near boundary to the laser and the vertical; and Θ is the assigned laser system buffer (half angle).

From Figure 7, the following relationships are readily apparent:

$$\tan \alpha = \frac{RL}{LA - NA} \tag{7}$$

and

$$\tan (\alpha + \Theta) = \frac{RL + RN}{LA} \tag{8}$$

A trigonometric identity exists that

$$\tan (\alpha + \Theta) = \frac{\tan \alpha + \tan \Theta}{1 - \tan \alpha \tan \Theta} \tag{9}$$

Setting Equation 8 equal to Equation 9 and substituting Equation 7 for tan α, one obtains:

$$\frac{RL + RN}{LA} = \frac{RL + (LA + NA) \tan \Theta}{LA + NA - RL \tan \Theta} \tag{10}$$

Equation 10 can now be rearranged to the standard form of:

$$ax^2 + bx + c = 0 \tag{11}$$

where

$x = LA$

$a = -\tan \Theta$

$b = RN - NA \tan \Theta$

and

$c = RL*NA + RN*NA - (RL)^2 \tan \Theta - RN*RL*\tan \Theta$

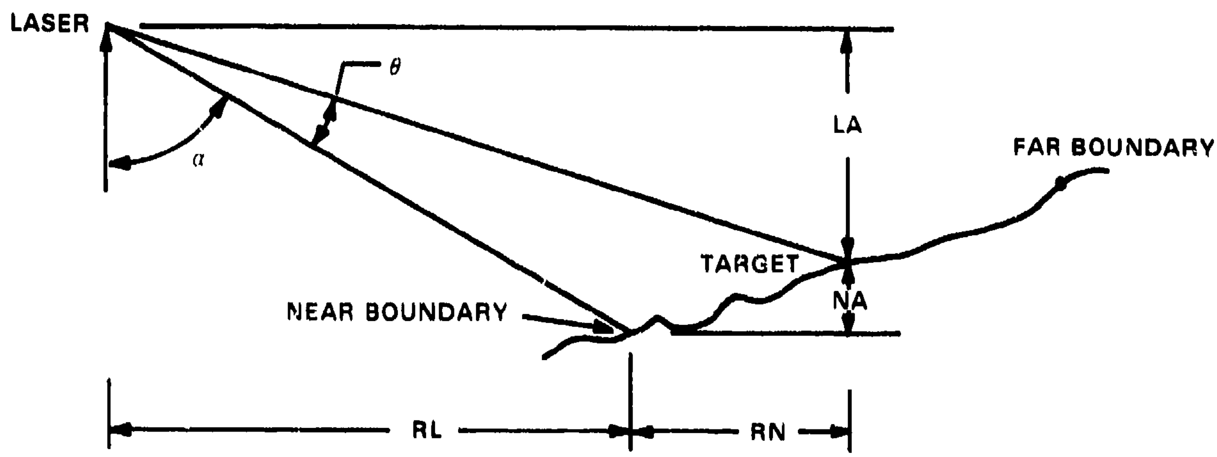

Figure 7. Near Boundary Geometry

Solving Equation 11 for x and taking the positive solution provide the minimum laser altitude for the near boundary constraint:

$$LA = x = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \tag{12}$$

Figure 8 illustrates the geometry for the far boundary constraint. In Figure 8, RF is the far boundary to target range, FA is the far boundary elevation above target, and RL + RN + RT is the laser-to-target range. RT is the length of the target area and for the case of a point target is equal to zero.

Following the same logic used for the near boundary constraint, the minimum laser altitude for the far boundary constraint is:

$$LA = x = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \tag{13}$$

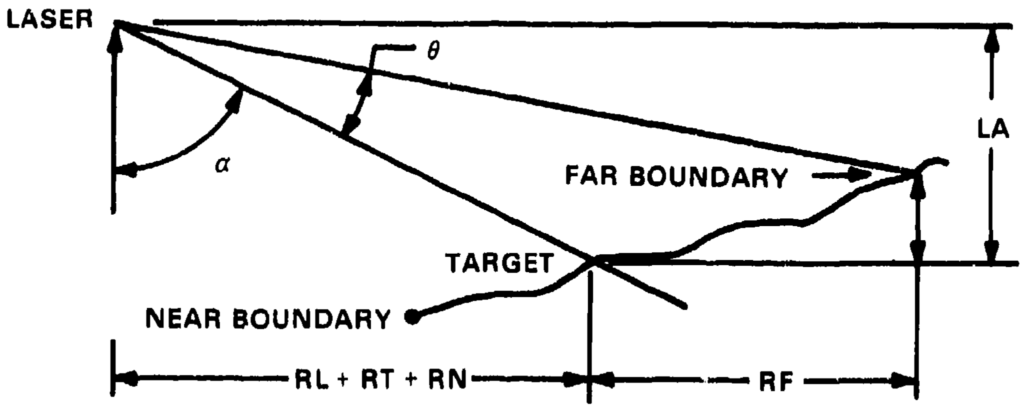

Figure 8. Far Boundary Geometry

where

$x = LA$

$a = -\tan\Theta$

$b = RF + FA*\tan\Theta$

and

$c = -(RL + RT + RN + RF)*(RL + RT + RN)*\tan\Theta + FA(RL + RT + RN)$

Solving both Equations 12 and 13 for LA and taking the more restrictive answer will provide the minimum safe laser altitude at a specified range. It should be noted that, if the slant range between laser and target is greater than the NOHD of the laser, the far boundary is not a limiting case and no hazard exists beyond the far range boundary. In this case, only the near boundary constraint need be satisfied.

With Specular Reflections

In most applications, such specular reflectors as mirrors, glass, or Plexiglas can be avoided either by appropriate selection of laser target location or physically removing them from the target area. Water, on the other hand, quite often cannot be avoided. The equations derived in the following paragraphs should, therefore, be applied as additional criteria whenever standing water is or is likely to be present in the target area.

Figure 9 illustrates the geometry involved if standing water is present in the target area. The standing water surface can be considered to always be horizontal, since any wave action will cause the water surface to be curved, resulting in a loss of collimation of the beam. Any reflections from the water surface will continue along the same azimuth as the primary beam and will be directed upwards at an angle equal to the incident angle.

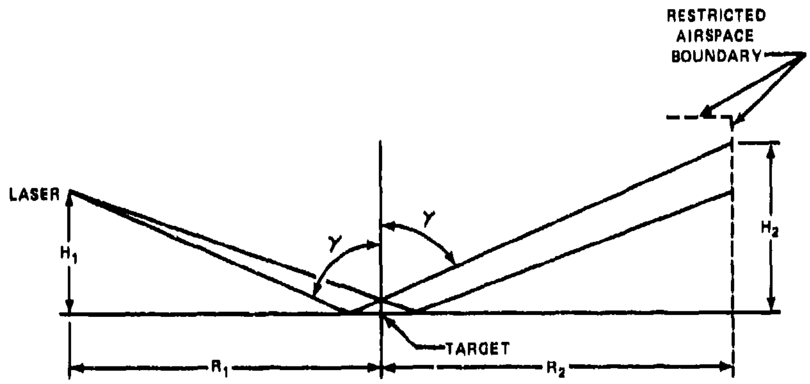

Figure 9. Standing Water Geometry

In Figure 9, R_1 is the laser-to-target range; H_1 is the laser elevation above target, R_2 is the target to restricted airspace boundary range, H_2 is the elevation of the reflected beam above target as it exits the restricted airspace, and γ is the angle of the direct and reflected beams to the horizontal.

From Reference 3, the radiant energy, H, at the point that the beam intercepts the restricted airspace boundary is

$$H = 2.6Q\left(1 - e^{-d^2/\left(a + \frac{H_1 + H_2}{\cos\gamma}\phi\right)^2}\right) e^{-\mu\left(\frac{H_1 + H_2}{\cos\gamma}\right)} K$$

where

$$K = \frac{P_{/\!/} \tan^2(\gamma - \gamma')}{\tan^2(\gamma + \gamma')} + \frac{P_{\perp}\sin^2(\gamma - \gamma')}{\sin^2(\gamma + \gamma')}$$

$$\gamma' = \sin^{-1}(\sin\gamma/N)$$

and

N = Index of retraction of the water

where Q is the output energy in joules, γ is the angle of the refracted laser beam in the water, $P_{\perp}$ is the fraction of the laser beam polarized perpendicular to the horizontal, $P_{/\!/}$ is the fraction of the laser beam polarized parallel to the horizontal, ϕ is the beam divergence in radians, and μ is the atmospheric attenuation coefficient. Current military laser rangefinders/designators are either circular polarized or unpolarized and both $P_{\perp}$ and $P_{/\!/}$ can be safely assumed to equal 0.5.

Equation 14 must now be solved for the minimum laser altitude, H_1, at which H is less than the appropriate MPE. Since this requires an iterative solution, the task is best performed by a computer code (see Appendix B). The highest altitude determined by this solution or the near and far boundary constraints discussed in the previous section is then the limiting factor.

SAMPLE APPLICATIONS

Assume that the A-6E TRAM laser is to be used on the range depicted in Figure 10. From Appendix A, the NOHD is 8.1 nmi (15 km) and the assigned buffer zone is 5 mrad. Choosing a laser to target range of 5 nmi, the minimum safe lasing altitude may be found by taking the worst case of the three constraints illustrated in the following paragraphs.

First, set up the variables relative to the target for the near boundary evaluation.

NA = +20 ft

RL = 30,380.6 ft

RN = 5000 ft

Equation 12 would be used for the minimum aircraft lasing altitude that will still constrain the beam and its associated buffer within the near boundary constraints as follows:

$$a = -\tan(5 \times 10^{-3}\,\text{rad}) = -5 \times 10^{-3}\ \text{rad}$$

$$b = 5000\ \text{ft} - (20\ \text{ft})\tan(5 \times 10^{-3}\ \text{rad}) = 4999.9\ \text{ft}$$

$$c = (30380.6\ \text{ft})(20\ \text{ft}) + (5000\ \text{ft})(20\ \text{ft}) - (30380.6\ \text{ft})^2 \tan\theta - (5000\ \text{ft})(30380.6\ \text{ft})\tan\theta = -4666852.07\ \text{ft}^2$$

$$LA = -4999.9\ \text{ft} + \frac{(4999.9\ \text{ft})^2 - 4\,(-5 \times 10^{-3}\ \text{rad})(-4666852.07\ \text{ft})}{2\,(-5 \times 10^{-3}\ \text{rad})}$$

$$LA = 934.26\ \text{ft}$$

Equation 13 would then be used to obtain the minimum altitude of the lasing aircraft that would constrain the laser beam and its associated buffer within the far boundary as follows:

FA = 25 ft

RL = 30380.6 ft

RN = 5000 ft

RT = 300 ft

RF = 5200 ft

$$RL + RN + RT = 30380.6 \text{ ft} + 5000 \text{ ft} + 300 \text{ ft} = 35680.6 \text{ ft}$$

$$(RL + RN + RT) + RF = 35680.6 \text{ ft} + 5200 \text{ ft} = 40880.6 \text{ ft}$$

$$a = -\tan (5 \times 10^{-3} \text{ rad}) = -5 \times 10^{-3}$$

$$b = RF + FA \tan \Theta = 5200 \text{ ft} + 25 \text{ ft} (\tan)(5 \times 10^{-3}) = 5203.125 \text{ ft}$$

$$c = -(RF + RN + RT + RF)(FL + RT + RN) \tan \Theta + FA(RL + RT + RN)$$

$$= -(40880.6 \text{ ft})(35680.6 \text{ ft}) \tan(5 \times 10^{-3} \text{ rad}) + 25 \text{ ft } (35680.6 \text{ ft})$$

$$= -6401267.457 \text{ ft}^2$$

$$LA = -5203.125 + \frac{\sqrt{(5203.125 \text{ ft})^2 - 4(-5 \times 10^{-3} \text{ rad})(-6401267.457 \text{ ft})}}{2(15 \times 10^{-3} \text{ rad})}$$

$$LA = 1231.7 \text{ ft}$$

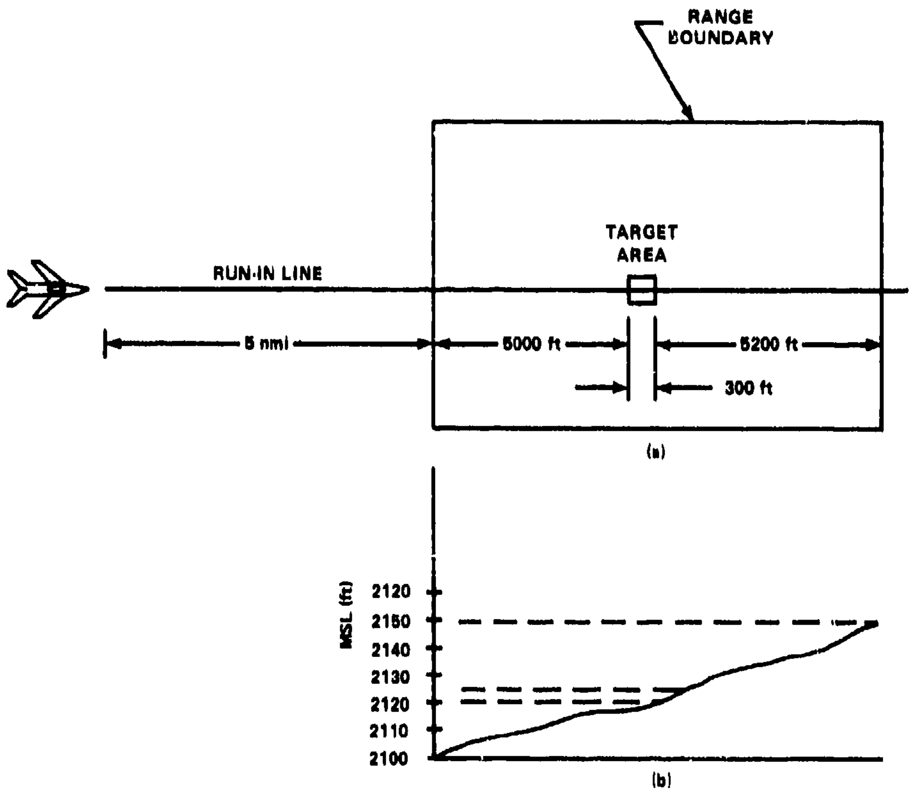

Figure 10. Example Range Geometry for Airborne Laser Operations, (a) Plan View and (b) Terrain Profile Relative to MSL Along Run-in Line

Clearly for this particular range of laser to target, the far boundary conditions are the most restrictive. The minimum aircraft altitude for firing the laser would be 1231.7 ft above the target or 3356.7 ft above MSL.

If standing water were present in the target area, one would need to consider the specular reflection hazard. Knowing the distance to and maximum altitude of the restricted airspace associated with the range, Equation 14 may be solved, using an iterative technique to determine the third constraint.

Based on the relative motion of both the laser and observer aircraft, the probability of receiving more than a single pulse exposure is considered extremely remote. The appropriate MPE for this instance would be the single pulse exposure standard of 5×10^{-6} joules per square centimeter. This would provide an NOHD of 5.1 nmi and the laser beam would therefore be safe for airborne observation prior to exiting the controlled range.

RESULTS

Methods have been developed to perform laser safety evaluations of Navy and Marine Corps ranges and have been used to assure the safety of laser operations on numerous ranges worldwide. Because airborne lasers are currently being deployed in increasing numbers, the basic approach and equations were derived for these systems. They are, however, equally applicable to ground-based lasers.

A microcomputer code, written in ANSI 77 FORTRAN, has been developed, which will provide safe flight profiles for airborne laser systems. The output of this code can also be used in establishing operating areas for ground-based lasers. Input to the code includes output parameters, NOHD and assigned buffer zone for the laser system, as well as parameters describing the geometry of the range.

CONCLUSIONS

The methods described can, if applied judiciously by a person knowledgable in lasers and laser safety, provide constraints under which a specified laser rangefinder/designator system or group of systems may be safety operated on a particular range. Only those restrictions necessary to assure the protection of civilian and military personnel are applied.

These methods should only be applied by personnel who are trained and experienced in the area of laser safety. Each range facility presents a unique set of problems; all of which cannot be adequately addressed in this report.

RECOMMENDATIONS

Shipboard laser systems are currently being developed. When these systems are deployed in the mid 1980s, the techniques described herein should be updated to include the special hazards of shipboard lasers. The lack of terrain features to act as a backstop in an open ocean environment and the relatively low elevation above the water, when combined with the longer NOHD of a more powerful shipboard laser system, will cause such factors as the curvature of the earth to play a significant role in shipboard laser safety evaluations.

LIST OF VARIABLES

Variable	Description
a	Diameter of laser output at 1/e peak power points
D	Diameter of laser beam at a specified distance from laser
E	Amplitude of Intensity
FA	Far boundary elevation relative to target
H	Radiant Energy (joules/cm^2)
H_1	Height of lasing aircraft above the target
H_2	Height of observing aircraft above the target
I	Irradiance at a distance R from laser (watts/cm^2)
Io	Irradiance at output of laser (watts/cm^2)
LA	Laser elevation above target
NA	Near boundary elevation relative to target
Po	Power of CW laser (watts) at output
$P_\perp$	Percentage of laser energy polarized perpendicular to plane of reflector
$P_{//}$	Percentage of laser energy polarized horizontal to plane of reflector
Q	Energy of pulsed laser (joules)
R	Distance downrange from laser
r	Radius of curvature of spherical wave
RF	Distance of target to far boundary
RL	Distance of laser to near boundary
RN	Distance of near boundary from target
RT	Target separation
R_1	Distance of lasing aircraft to target
R_2	Distance of observing aircraft to target
γ	Angle of incidence for laser beam relative to plane of reflector
μ	Atmospheric attenuation coefficient
Θ	Buffer angle
ϕ	Beam Divergence (full angle)

REFERENCES

1. CHNAVMAT message 071656Z Mar 79.

2. ANSI Z136.1--1980, American National Standard for the Safe Use of Lasers (6 June 1980).

3. D. Sliney and M. Wolbarsht, *Safety with Lasers and Other Optical Sources--A Comprehensive Handbook* (1980 Plenum Press, New York).

4. Wesley J. Marshall, "Hazard Analysis on Gaussian Shaped Laser Beams," *American Industrial Hygiene Association Journal ('41)*, August 1980.

5. D. L. Jenkins, *Nonionizing Radiation Protection Special Study No. 25-42-0327-80 Hazard Evaluation of the A-6E Target Recognition Attack Multisensor Laser System* (U), U. S. Army Environmental Hygiene Agency, (Aberdeen Proving Ground, Maryland, January-February 1980).

6. D. L. Jenkins and D. W. Griffis, *Nonionizing Radiation Protection Special Study No. 25-42-0325-81 Hazard Evaluation of the Production Model AN/AAS-37 Laser System Mounted on the OV-10 Aircraft* (U), U. S. Army Environmental Hygiene Agency (Aberdeen Proving Ground, Maryland, May-August 1980).

7. D. H. Sliney, *Nonionizing Radiation Protection Special Study No. 25-42-0320-80 Hazard Evaluation of the AN/AVQ-25 Pave Tack Laser Rangefinder/Designator on the F-111F Aircraft, Engineering Development Model* (U), U. S. Army Environmental Hygiene Agency (Aberdeen Proving Ground, Maryland, March 1980).

APPENDIX A

SAFETY PARAMETERS OF CURRENTLY DEPLOYED LASER SYSTEMS

Table A-1 provides information on laser systems currently deployed or in the later stages of engineering development, which are likely to be used on Navy and Marine Corps range facilities. This information is necessary to a complete and meaningful evaluation of the system's use on the range.

All the lasers addressed in Table A-1 are Class IV, high-power lasers and are either randomly or circularly polarized. Other system parameters and detailed hazard analyses of the systems may be found in the source data reference documents (References A-1 through A-6).

Table A-1. Laser System Safety Parameters

	A-6E TRAM	OV-10D NOS	F-111F Pave Tack	F-4E Pave Spike	MULE	GLLD
NOHD (Single Pulse) (km)		7.1	8.8	6.8	6.5	8.0
NOHD (Multipulse) (km)	14.6	11.2	16.0	10.0	20.0	25.0
NOHD (8-cm Objective Lens) (km)	58.0	56.2	52.0	48.0	See Note 4	See Note 4
NOHD (Diffuse Reflections)	0	0[1]	0[3]	0	0	0
Assigned Buffer Zone (mrad)	5	5	5	5	See Note 5	2[7]
Skin Hazard Range (m)	47	See Note 2	47	0	0	See Note 8
Eye Protection (Unaided Viewing) OD	4.6	5.2	4.3	4.2	3.9	3.8
Eye Protection (Aided Viewing) OD	5.8	5.6	5.8	5.6	5.6	5.5
Source Data Reference	A-1	A-2	A-3	A-4	A-5	A-6

NOTES:

1. Due to an apparent focus between 25 and 35 m from the exit port, a diffuse white target placed at this distance will produce a hazardous diffuse reflection.

2. A specific skin hazard distance is not given in the basic reference. Skin hazards from lasers of this power level are, however, usually not adequately severe to be of significant concern.

3. Due to a focus between 50 and 150 meters from the exit port, a diffuse white target placed at this distance will produce a hazardous diffuse reflection.

4. NOHD = 35 km (single pulse) 79 km (multipulse)

5. Buffer = 2 mrad (stabilized tracking tripod module used) or 10 mrad (hand held)

6. NOHD = 40 km (single pulse) or 80 km (multipulse)

7. Buffer = 2 mrad (stabilized mount used)

8. The GLLD laser only marginally exceeds the protection standard for pulse repetition rates greater than 19.

REFERENCES

A-1. D. L. Jenkins, *Nonionizing Radiation Protection Special Study No. 25-42-0327-80, Hazard Evaluation of the A-6E Target Recognition Attack Multisensor Laser System* (U), U. S. Army Environmental Hygiene Agency (Aberdeen Proving Ground, Maryland, January-February 1980).

A-2. D. L. Jenkins and D. W. Griffis, *Nonionizing Radiation Protection Special Study No. 25-42-0325-81 Hazard Evaluation of the Production Model AN/AAS-37 Laser System Mounted on the OV-10 Aircraft* (U), U.S. Army Environmental Hygiene Agency (Aberdeen Proving Ground, Maryland, May-August 1980).

A-3. D. H. Sliney, *Nonionizing Radiation Protection Special Study No. 25-42-0320-80 Hazard Evalution of the AN/AVQ-25 PAVE TACK Laser Rangefinder/Designator on the F-111F Aircraft, Engineering Development Model* (U), U. S. Army Environmental Hygiene Agency (Aberdeen Proving Ground, Maryland, March 1980).

A-4. T. L. Lyon and D. W. Griffis, *Nonionizing Radiation Protection Special Study No. 25-42-0304-80, Hazard Evaluation of the Production Model PAVE SPIKE AN/ASQ-153 Target Designator System, With AN/AVQ-23 Pod Laser on the F-4E Aircraft*, U. S. Army Environmental Hygiene Agency (Aberdeen Proving Ground, Maryland, 28-30 April 1980).

A-5. T. L. Lyon and W. J. Marhsall, *Nonionizing Radiation Protection Special Study No. 25-42-0305-81, Hazard Evaluation of the Engineering Development Model Modular Universal Laser Equipment (MULE) AN/PAQ-3 Laser* (U), U. S. Army Environmental Hygiene Agency (Aberdeen Proving Ground, Maryland, 5-6 November 1980).

A-6. T. L. Lyon and D. L. Jenkins, *Nonionizing Radiation Protection Special Study No. 25-42-0391-79, Evaluation of the Engineering Development Model Laser Designator Rangefinder (LDR) of the Ground Laser Locator Designator (GLLD) System* (U), U. S. Army Environmental Hygiene Agency (Aberdeen Proving Ground, Maryland, September-December 1978).

APPENDIX B

COMPUTER PROGRAM FOR RANGE EVALUATIONS

The following program was written in ANSI 77 FORTRAN for use on an APPLE II PLUS Microcomputer with two disc drives and an EPSON MX-80 Printer. External graphics capability had not been developed at the time of publication so it is not included in this program. Due to the limited amount of memory available, the dimensioned arrays have been kept small. All of these arrays can be increased for larger micro or main frame computers.

Due to the limited speed available on the APPLE, the approach was to provide the maximum options available with a minimum of hands-on time. This would allow the operator to work on other jobs, while the computation and printer operations were in process. The same approach will be used on the external graphics once the plotter and interface are included in the system.

A block diagram of the main program is included to aid the reader in following the flow of the option selections. Block diagrams at the subroutines have not been included, since it is relatively easy to follow the flow of the programs. A table of variables and their meanings are included for each individual subroutine and the main program. The subroutines are loaded into core as overlays to reduce the amount of memory used. This facilitates main program expansion, as required.

Figure B-1 illustrates the variables used in computing the minimum altitude of the lasing aircraft for the boundary conditions closest to the aircraft. Refer to the main text for the derivation and form of the equation used.

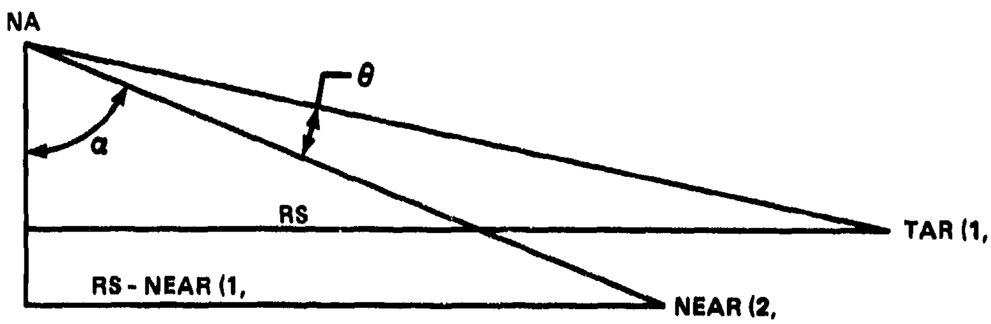

Figure B-1. Near Boundary Range Evaluation Using Variables in Computer Subroutine COMPU

Figure B-2 illustrates the variables used in computing line-of-sight clearance and the appropriate buffer for peak clearance, if a terrain peak is between the lasing aircraft and the target. In the subroutine COMPU, the minimum altitude calculated for the near boundary is evaluated to determine if appropriate line of sight exists between the lasing aircraft and the near boundary. The formula used is as follows:

TEST = NEAR(1,I) + ((RS - NEAR(2,I)) + (PEAKS(1,I,k) - NEAR(1,I,)/
(PEAKS)(2,I,k) - NEAR(2,I)))

where

I = the run number being evaluated

K = the peak number being evaluated

The derivation is as follows:

$$\tan(a) = \frac{RS - NEAR(1,I)}{NA - NEAR(2,I)}$$

tan(a) also equals $\frac{RS - PEAKS(1,I,K)}{NA - PEAKS(2,I,K)}$

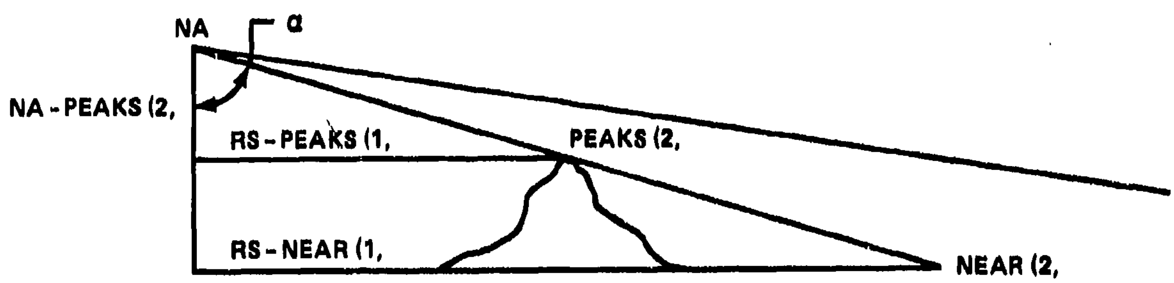

Figure B-2. Variables Used to Evaluate Peak Line of Sight

therefore

$$\frac{RS - NEAR(1,I)}{NA - NEAR(2,I)} = \frac{RS - PEAKS(1,J,K)}{NA - PEAKS(2,I,K)}$$

and

(RS - NEAR(1,I))*NA - PEAKS(2,I,K)*RS - NEAR(1,I))

= NA(RS - PEAKS(1,I,K) - NEAR(2,I)*(RS - PEAKS)(1,I,K)

Solving for NA

NA = (PEAKS(2,I,K)*(RS - NEAR(1,I)) - (NEAR(2,I)*(RS - PEAKS(1,I,K)
/(PEAKS(1,I,K) - NEAR(1,I))

If this value of NA is below that calculated from the near boundary parameters, than it is ignored as adequate clearance exists. If this value is above the NA previously calculated, than a new NA must be calculated according to the variables of Figure B-3. Derivation of the formula used is as follows:

$$\tan(\alpha + \Theta) = \frac{RS}{NA - TAR(1,I)}$$

$$\tan(\alpha) = \frac{RS - PEAKS(2,I,K)}{NA - PEAKS\ (1,I,K)}$$

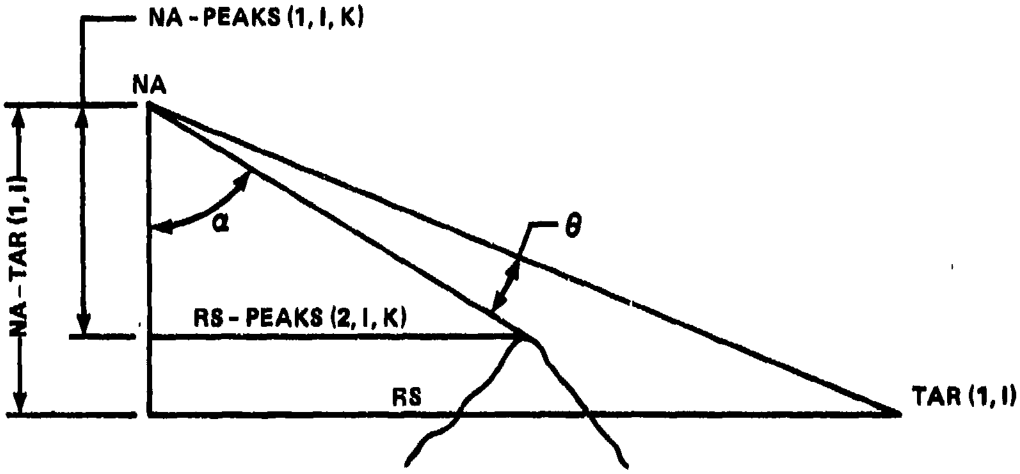

Figure B-3. Variables Used to Calculate a Peak Clearance Equal to at Least the Laser System Buffer Zone

$$\tan\ (\alpha + \Theta) = \frac{\tan\ \alpha + \tan\ \Theta}{1 - \tan\ \alpha\ \tan\ \Theta}$$

$$\frac{RS}{NA - TAR(1,I)} = \frac{\dfrac{RS - PEAKS(2,I,K)}{NA - PEAKS(1,I,K)} + \tan\ \Theta}{1 - \dfrac{RS - PEAKS(2,I,K)}{NA - PEAKS(1,I,K)}\ \tan\ \Theta}$$

Multiplying the numerator and denominator of the righthand expression by (NA - PEAKS(1,I,K)) results in the following equation:

$$\frac{RS}{NA - TAR\ (1,I)} = \frac{RS - PEAKS(2,I,K) + NA\ TAN\ \Theta - PEAKS(1,I,K)TAN\ \Theta}{NA - PEAKS(1,I,K) - RS\ TAN\ \Theta + PEAKS(2,I,K)TAN\ \Theta}$$

Performing the necessary operations to obtain the form of Equation 14, one obtains

$$NA = \frac{-BP + \sqrt{(BP) - 4*AP*CP}}{2AP}$$

where

$$AP = TAN\ \Theta$$

$$BP = -PEAKS(1,I,K)*TAN\ \Theta - TAR(1,I)*TAN\ \Theta - PEAKS(2,I,K)$$

$$\begin{aligned} CP = {} & RS*PEAKS(1,I,K) + RS^2 TAN\ \Theta - RS*PEAKS(2,I,K)*TAN\ \Theta \\ & -RS*TAR(1,I) + TAR(1,I)*PEAKS(2,I,K) + TAR(1,I)*PEAKS \\ & (1,I,K)*TAN\ \Theta \end{aligned}$$

The far boundary solution for a minimum altitude follows a similar approach. Figure B-4 illustrates the variables and their associated meanings. The derivation of the equation used can be found in the main text.

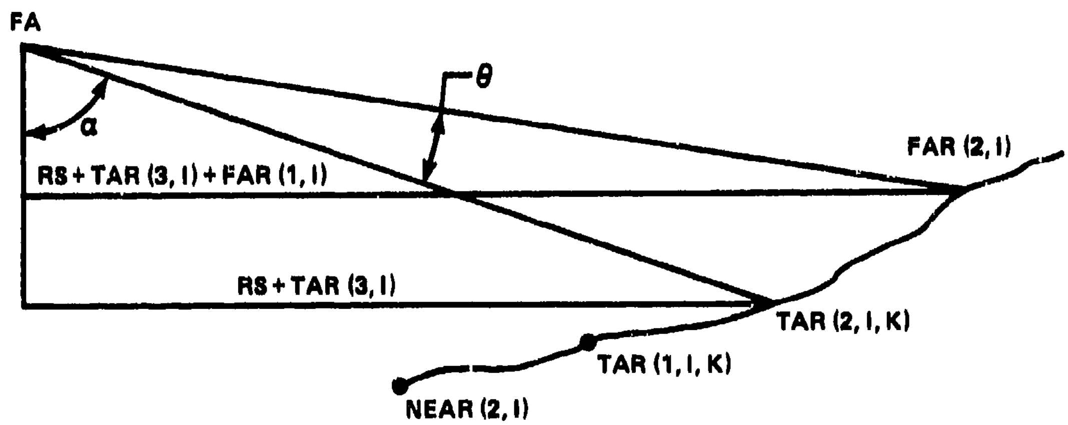

Figure B-4. Variables Used to Evaluate the Minimum Altitude Required to Maintain the Laser Beam and its Associated Buffer Within the Controlled Range Areas Farthest from the Laser

Upon obtaining a minimum altitude for the far boundary, this value is compared with the near boundary minimum altitude. The highest value is chosen for the minimum altitude for that particular range to target on that particular run.

If specular reflections are present, i.e., reflections off water, then the program calculates the altitude of the lasing aircraft required to reduce the energy value to at least the protection standards within the restricted air-space boundaries.

```
$USES UDISKR IN FORT2:DISKR.CODE OVERLAY
$USES UCOMPU IN FORT2:COMPU.CODE OVERLAY
$USES UPRINT IN FORT2:PRINT.CODE OVERLAY

      PROGRAM RANGE
      DIMENSION NEAR(2,10),FAR(2,10),TAR(3,10),LASER(10,2,150),
     1RUN(10),PEAKS(2,10,10),NPEAKS(10),NDATA(10),COM(10),
     2RPRINT(10),AIR(2,10),IFLAG(10),RST(10)
      REAL NEAR,FAR,TAR,LASER,PEAKS,NOHD,K1,START,BUF,INC
      INTEGER ROPT,POPT,WOPT,GOPT,NRUN,NPEAKS,NDATA,RPRINT,COM,
     1FNUM,NADD
      CHARACTER RUN*20,TITLE*20,ANS*1,FNAMR*25,FNAMW*25
      COMMON/READ/NEAR,FAR,TAR,PEAKS,LASER,NDATA,NPEAKS,UNNOHD,OPNOHD,
     1BUF/COMP/AIR,IFLAG,AINOHD,D,A,DIV,Q,ATMOS,P1,P2,RST
      COMMON/CHAR/TITLE,RUN
C SELECT READ OPTIONS
      K1=6076.1155
      WRITE (*,100)'READ OPTIONS :'
      WRITE (*,105)'1 = READ DATA ONLY'
      WRITE (*,105)'2 = READ DATA & ADD RUNS'
      WRITE (*,105)'3 = CREATE NEW DATA'
      WRITE (*,110)'SELECT READ OPTION'
      READ  (*,115)ROPT
      GOTO (36,36,37)ROPT
36    WRITE(*,'(A$)')'READ FILE NAME :'
      READ (*,'(A)')FNAMR
C SELECT WRITE OPTIONS
37    WRITE (*,100)'WRITE OPTIONS :'
      WRITE (*,105)'1 = WRITE TO DATA FILE'
      WRITE (*,105)'2 = NO WRITE'
      WRITE (*,110)'SELECT WRITE OPTION'
      READ  (*,115)WOPT
      GOTO (38,39)WOPT
38    WRITE(*,'(A$)')'WRITE FILE NAME :'
      READ (*,'(A)')FNAMW
C SELECT PRINTER OPTIONS
39    WRITE (*,100)'PRINTER OPTIONS :'
      WRITE (*,105)'1 = PRINT ALL RUNS'
      WRITE (*,105)'2 = PRINT SELECTED RUNS'
      WRITE (*,105)'3 = NO PRINTER OUTPUT'
      WRITE (*,110)'SELECT PRINTER OPTION'
      READ  (*,115)POPT
      GOTO (33,33,35)POPT
33    WRITE(*,'(A$)')'INCREMENTS FOR DATA PRINT ='
      READ (*,'(F8.2)')INC
C READ DISK OR ENTER RUN DATA USING DISKR SUBROUTINE
35    K3=1
      CALL DISKR(K3,NRUN,FNAMR,ROPT,NADD,PS)
C NOW LIST ALL RUNS FOR PRINTER OPTIONS 2 OR 3
50    GOTO (41,42,41)POPT
C DETERMINE HOW MANY RUNS ARE PRESENT
42    GOTO (43,44,44)ROPT
C DETERMINE NWRIT FOR ROPT=1
43    NWRIT=NRUN
      GOTO 45
C DETERMINE NWRIT FOR ROPT=2 OR 3
44    NWRIT=NADD
C NOW LIST ALL RUNS
45    GOTO (51,52,52)ROPT
```

```
52      DO 46 I=1,NWRIT
        WRITE(*,135)I,RUN(I)
46      CONTINUE
        OPEN(6,FILE='PRINTER:',FORM='UNFORMATTED')
        WRITE(6)7
        CLOSE(6)
C NOW SELECT RUNS FOR PRINTOUT OR COMPOSITE
51      GOTO (41,47,41)POPT
C SELECT RUNS FOR PRINTING SELECTED RUNS
47      WRITE(*,110)'# OF RUNS FOR PRINTING='
        READ (*,115)NPRINT
        DO 22 I=1,NPRINT
        WRITE(*,110)'RUN # TO BE PRINTED ='
        READ (*,115)RPRINT(I)
22      CONTINUE
        GOTO 41
41      GOTO (4,49,49)ROPT
C NOW COMPUTE ALL RUNS THAT DO NOT HAVE DATA
49      CALL COMPU(NRUN,NADD,PS)
        WRITE(*,'(A)')'FINISHED WITH COMPUTE'
        NRUN=NADD
C DISK WRITING OPTIONS
4       GOTO (15,16)WOPT
15      WRITE(*,'(A)')'DISK WRITING OPTION'
        K3=2
        CALL DISKR (K3,NRUN,FNAMW,ROPT,NADD,PS)
C PRINTER OPTIONS
16      GOTO (17,18,20)POPT
C PRINT ALL RUNS
17      DO 21 I=1,NRUN
        CALL PRINT (I,INC)
21      CONTINUE
        GOTO 20
C PRINT SELECTED RUNS
18      DO 23 I=1,NPRINT
        DO 24 J=1,NRUN
        IF (J.EQ.RPRINT(I)) THEN
        CALL PRINT(J,INC)
        GOTO 23
        ENDIF
24      CONTINUE
23      CONTINUE
20      STOP
100     FORMAT (A)
105     FORMAT (3X,A)
110     FORMAT (A$)
115     FORMAT (BN,I3)
120     FORMAT (A,I3,A$)
125     FORMAT (F8.2)
130     FORMAT (A,I3,A,A)
135     FORMAT (2X,I3,'=',A)
        END
```

```
      SUBROUTINE DISKR(K3,NRUN,FNAME,ROPT,NADD,PS)
      DIMENSION NEAR(2,10),FAR(2,10),LASER(10,2,150),TAR(3,10),RST(10),
     1PEAKS(2,10,10),NPEAKS(10),NDATA(10),RUN(10),AIR(2,10),IFLAG(10)
      CHARACTER TITLE*20,RUN*20,FNAME*25,ANS*1,FDISK*5,AREF*1
      REAL NEAR,FAR,TAR,LASER,PEAKS,NOHD,BUF
      INTEGER NDATA,NRUN,NPEAKS,FNUM,NADD,ROPT
      COMMON/READ/NEAR,FAR,TAR,PEAKS,LASER,NDATA,NPEAKS,
     1UNNOHD,OPNOHD,BUF/CHAR/TITLE,RUN/COMP/AIR,IFLAG,AINOHD,D,A,DIV,
     2Q,ATMOS,P1,P2,RST
C IF K3=2 THEN GO TO WRITE PORTION OF SUBROUTINE,OTHERWISE READ
      GOTO (40,41)K3
40    GOTO (1,1,2)ROPT
1     OPEN (6,FILE=FNAME,STATUS='OLD',FORM='UNFORMATTED')
      K4=0
      READ (6)TITLE
      WRITE(*,225)TITLE
      READ (6) UNNOHD,OPNOHD,BUF
      READ (6) NRUN
      DO 10 I=1,NRUN
      READ(6)RUN(I)
      WRITE(*,230)I,RUN(I)
      READ (6) NEAR(1,I),NEAR(2,I),FAR(2,I),FAR(1,I)
      READ (6) TAR(1,I),TAR(2,I),TAR(3,I)
      READ (6) NPEAKS(I)
      IF (NPEAKS(I).GT.0) THEN
      DO 20 J=1,NPEAKS(I)
      READ (6) PEAKS(1,I,J),PEAKS(2,I,J)
20    CONTINUE
      ENDIF
      READ (6) NDATA(I)
      DO 30 J=1,NDATA(I)
      READ (6) LASER(I,2,J),LASER(I,1,J)
30    CONTINUE
10    CONTINUE
      CLOSE (6)
      GOTO (4,3,2) ROPT
C FIND NO OF ADDITIONS IF READ OPTION IS 2
C OBTAIN TITLE, NOHD, BUFFER ANGLE AND NO OF RUNS IF READ OPTION IS 3

C INPUT FOR NEW DATA FILE
2     WRITE (*,110)'NO OF RUNS ='
      READ (*,115)NADD
      NRUN=1
      WRITE(*,110)'TITLE ='
      READ (*,100)TITLE
      WRITE (*,110)'NOHD (UNAIDED VIEWING )(N MI)='
      READ (*,125)UNNOHD
      UNNOHD=UNNOHD*6076.12
      WRITE (*,110)'NOHD (W/OPTICS)(N MI) ='
      READ (*,125)OPNOHD
      OPNOHD=OPNOHD*6076.12
      WRITE (*,110)'BUFFER ANGLE (M RAD) ='
      READ (*,125)BUF
      BUF=BUF*.001
      GOTO 8
C INPUT FOR ADDITIONAL RUNS TO EXISTING DATA FILE
3     WRITE (*,110)'NO OF ADDITIONS ='
      READ (*,115)NADD
      NADD=NRUN+NADD
```

```
      NRUN=NRUN+1
C INPUT FOR ALL NEW RUNS
8     WRITE(*,110)'WATER REFLECTIONS PRESENT?'
      READ (*,100)ANS
      IF (ANS.EQ.'Y') THEN
      K4=1
      WRITE (*,100)'OUTPUT PARAMETERS FOR LASER:'
      WRITE (*,135)'  ENERGY (J OR W) ='
      READ (*,125)Q
      WRITE (*,135)'BEAM DIAMETER (CM)='
      READ (*,125)A
      WRITE (*,135)'DIVERGENCE (M RAD)='
      READ (*,125)DIV
      DIV=DIV*1.E-3
      WRITE (*,135)'ATMOS ATTEN(X10-7)='
      READ (*,125)ATMOS
      ATMOS=ATMOS*1.E-7
      WRITE (*,135)'    APERTURE (CM) ='
      READ (*,125)D
      WRITE (*,135)'NOHD FOR AIR(N MI)='
      READ (*,125)AINOHD
      AINOHD=AINOHD*6076.12
      WRITE (*,135)'PS FOR AIR (X10-6)='
      READ (*,125)PS
      PS=PS*1.E-6
      WRITE(*,100)'POLARIZATION :'
      WRITE(*,100)'   1 = PERPENDICULAR'
      WRITE(*,100)'   2 = HORIZONTAL'
      WRITE(*,100)'   3 = RANDOM'
      WRITE(*,110)'POLARIZATION ='
      READ (*,115)IP
      IF (IP.EQ.1) THEN
      P1=1.0
      P2=0.
      ELSEIF (IP.EQ.2) THEN
      P1=0.
      P2=1.
      ELSEIF (IP.EQ.3) THEN
      P1=0.5
      P2=0.5
      ENDIF
      ENDIF
      DO 5 I=NRUN,NADD
      WRITE (*,120)'RUN # ',I,' HEADING ='
      READ (*,100)RUN(I)
      WRITE(*,135)'STARTING RANGE (N M)='
      READ (*,125)START
      NDATA(I)=INT(START*10)
      RST(I)=START*6076.1155
      IFLAG(I)=0
      IF (K4.EQ.1) THEN
      WRITE (*,110)'WATER REFLECTIONS FOR THIS RUN?'
      READ (*,100)AREF
      IF (AREF.EQ.'Y') THEN
      IFLAG(I)=1
      WRITE (*,110)'DISTANCE, TGT TO AIRSPACE BOUND ='
      READ (*,125)AIR(1,I)
      WRITE (*,110)'ALTITUDE, AIRSPACE RESTRICTION='
      READ (*,125)AIR(2,I)
      ENDIF
      ENDIF
      WRITE (*,110)'NEAR BOUNDARY ALTITUDE (FT) ='
      READ (*,125)NEAR(1,I)
      WRITE (*,110)'             DISTANCE TO TGT ='
      READ (*,125)NEAR(2,I)
      IF (IFLAG(I).EQ.1) THEN
```

```
      FAR(1,I)=0.
      FAR(2,I)=AIR(1,I)
      GOTO 50
      ENDIF
      WRITE (*,110)'      FAR BOUNDARY ALTITUDE ='
      READ (*,125)FAR(1,I)
      WRITE (*,110)'             DISTANCE TO TGT ='
      READ (*,125)FAR(2,I)
50    WRITE (*,110)'           NEAR TGT ALTITUDE ='
      READ (*,125)TAR(1,I)
      WRITE (*,110)'            FAR TGT ALTITUDE ='
      READ (*,125)TAR(2,I)
      WRITE (*,110)'              TGT SEPERATION ='
      READ (*,125)TAR(3,I)
      WRITE (*,110)'NO OF PEAKS ='
      READ (*,115)NPEAKS(I)
      IF (NPEAKS(I).GT.0) THEN
      DO 6 J=1,NPEAKS(I)
      WRITE (*,110)'PEAK ALTITUDE ='
      READ (*,125)PEAKS(1,I,J)
      WRITE (*,110)'RANGE TO TGT  ='
      READ (*,125)PEAKS(2,I,J)
6     CONTINUE
      ENDIF
      WRITE (*,110)'IS DATA CORRECT ?'
      READ (*,100)ANS
      IF (ANS.EQ.'N') THEN
      GOTO 7
      ENDIF
5     CONTINUE
4     RETURN
C WRITING TO A DATA FILE
41    OPEN (6,FILE=FNAME,STATUS='NEW',FORM='UNFORMATTED')
      WRITE(6)TITLE
      WRITE(6)UNNOHD,OPNOHD,BUF
      WRITE(6)NRUN
      DO 42 I=1,NRUN
      WRITE(6)RUN(I)
      WRITE(6)NEAR(1,I),NEAR(2,I),FAR(2,I),FAR(1,I)
      WRITE(6)TAR(1,I),TAR(2,I),TAR(3,I)
      WRITE(6)NPEAKS(I)
      IF (NPEAKS(I).GT.0) THEN
      DO 43 J=1,NPEAKS(I)
      WRITE(6)PEAKS(1,I,J),PEAKS(2,I,J)
43    CONTINUE
      ENDIF
      WRITE(6)NDATA(I)
      DO 44 J=1,NDATA(I)
      WRITE(6)LASER(I,2,J),LASER(I,1,J)
44    CONTINUE
42    CONTINUE
      ENDFILE 6
      CLOSE (6,STATUS='KEEP')
      RETURN
100   FORMAT (A)
105   FORMAT (3X,A)
110   FORMAT (A$)
115   FORMAT (BN,I3)
120   FORMAT (A,I3,A$)
125   FORMAT (F8.2)
130   FORMAT (A,I3,A,A)
200   FORMAT (A)
205   FORMAT (F8.2,E8.2)
210   FORMAT (I3)
215   FORMAT (4F8.2)
220   FORMAT (3F8.2)
225   FORMAT ('THIS FILE CONTAINS DATA ON ',A)
230   FORMAT ('RUN # ',I3,' HAS ',A)
135   FORMAT (3X,A$)
      END
```

```
      SUBROUTINE COMPU(NRUN,NADD,PS)
C THIS SUBROUTINE COMPUTES MINIMUM ALTITUDE RESTRICTIONS FROM GIVEN RANGE
C DATA
      DIMENSION NEAR(2,10),LASER(10,2,150),FAR(2,10),TAR(3,10),RST(10),
     1PEAKS(2,10,10),NPEAKS(10),NDATA(10),AIR(2,10),IFLAG(10),ALT(120)
      REAL NEAR,FAR,TAR,LASER,PEAKS,NOHD,BUF,NA,K1,K2,K3
      INTEGER NDATA,NRUN,NPEAKS
      COMMON/READ/NEAR,FAR,TAR,PEAKS,LASER,NDATA,NPEAKS,UNNOHD,OPNOHD,
     1BUF/COMP/AIR,IFLAG,AINOHD,D,A,DIV,Q,ATMOS,P1,P2,RST
C OBTAIN LOWEST ALTITUDE
      DO 30 I=NRUN,NADD
      RS=RST(I)
      SMALL=NEAR(1,I)
      IF (TAR(1,I).LT.SMALL) THEN
      SMALL=TAR(1,I)
      ENDIF
      IF (TAR(2,I).LT.SMALL) THEN
      SMALL=TAR(2,I)
      ENDIF
      IF (FAR(1,I).LT.SMALL) THEN
      SMALL=FAR(1,I)
      ENDIF
      DO 10 J=1,NDATA(I)
C COMPUTE ALTITUDE RESTRICTION FROM NEAR BOUNDARY CONDITIONS
      AN=TAN(BUF)
      BN=-NEAR(2,I)-(AN*(NEAR(1,I)+TAR(1,I)))
      K1=TAR(1,I)*(-RS+NEAR(2,I))
      K2=NEAR(1,I)*((AN*TAR(1,I))-RS)
      K3=AN*RS*(RS-NEAR(2,I))
      CN=K1-K2+K3
      K1=BN**2
      K2=4*AN*CN
C IF FOLLOWING IS TRUE, NO BUFFER IS AVAILABLE
      IF (K2.GT.K1) THEN
      NA=-UNNOHD
C NO MORE COMPUTATION REQUIRED FOR THIS DISTANCE
      GOTO 10
      ENDIF
C ELSE COMPUTE ALTITUDE RESTRICTION,NEAR BOUNDARY
      NA=(-BN-(SQRT(K1-K2)))/(2*AN)
C IF PEAKS PRESENT,INSURE BUFFER IS AVAILABLE OVER PEAK AND LINE OF SIGHT
C TO TARGET IS AVAILABLE
      IF (NPEAKS(I).GT.0) THEN
      DO 20 K=1,NPEAKS(I)
      IF (RS.GT.PEAKS(2,I,K)) THEN
      K1=((RS-PEAKS(2,I,K))**2)+((NA-PEAKS(1,I,K))**2)
      K2=(SQRT(K1))*AN
      K3=NA-(PEAKS(1,I,K)+K2)
      X=(RS-PEAKS(1,I,K))/K3
      TEST=(RS-NEAR(2,I))/(NA-NEAR(1,I))
C IF THIS IS FALSE, THEN ADEQUATE CLEARANCE BY NEAR BOUNDARY ALTITUDE IS
C AVAILABLE
      IF (X.LT.TEST) THEN
      K1=(RS*PEAKS(1,I,K))-(NEAR(2,I)*PEAKS(1,I,K))
      K2=(RS*NEAR(1,I))-(NEAR(1,I)*PEAKS(2,I,K))
      K3=K1-K2
      NA=K3/(PEAKS(2,I,K)-NEAR(2,I))
      ENDIF
      ENDIF
```

```
20    CONTINUE
      ENDIF
C DETERMINE IF HYPOTENUSE IS LESS THEN OPTICS NOHD
      TEST=SQRT(((RS+TAR(3,I)+FAR(2,I))**2)+((NA-FAR(1,I))**2))
C IF IT IS LESS, THEN COMPUTE ALTITUDE RESTRICTION FOR FAR BOUNDARY
      K=1
      KS=1
      IRUN=0
      IF (TEST.GT.OPNOHD) THEN
      GOTO 6
      ENDIF
C IF REFLECTIONS ARE PRESENT THEN GO TO PART TWO
      IF (IFLAG(I).EQ.1) THEN
      GOTO 2
      ENDIF
C IF NOT THEN COMPUTE ALTITUDE FOR BUFFER
      RFAR=FAR(2,I)
      K1=RS+TAR(3,I)+FAR(2,I)
      K2=RS+TAR(3,I)
      BF=K2-K1-(TAR(2,I)*AN)-(FAR(1,I)*AN)
      K3=(K1*TAR(2,I))+(K1*K2*AN)-(FAR(1,I)*K2)
      CF=K3+(FAR(2,I)*TAR(2,I)*AN)
      K1=BF**2
      K2=4*AN*CF
C IF THE FOLLOWING IS TRUE THEN NO BUFFER EXISTS
      IF (K2.GT.K1) THEN
      NA=-UNNOHD
C NO FARTHER CALCULATION IS REQUIRED FOR THIS DISTANCE
      GOTO 40
      ENDIF
C OTHERWISE CALCULATE FAR BOUNDARY ALTITUDE RESTRICTIONS
      FA=(-BF-(SQRT((BF**2)-(4*AN*CF))))/(2*AN)
      IF (IFLAG(I).EQ.0) THEN
      GOTO 3
      ENDIF
C WATER REFLECTIONS ARE INVOLVED
C SET ALL DISTANCES TO CM AND ESTABLISH AN INITIAL ALTITUDE
2     R3=RS*30.48
      A1=AIR(1,I)*30.48
      R1=5000.*30.48
      RH=10000.*30.48
      RL=0.
      TR=TAR(3,I)*30.48
      TA=TAR(2,I)*30.48
      IF (TA.GT.R1) THEN
      R1=TA
      ENDIF
C FIND DISTANCE FROM TARGET TO MAINTAIN THE BUFFER
1     THETA=BUF+(ATAN((R3+TR)/(R1-TA)))
      RFAR=(R1*(TAN(THETA)))-(R3+TR)
      A2=A1-RFAR
      R2=A2/(TAN(THETA))
C NOW DETERMINE THE ENERGY AT THE BOUNDARY
      DIST=(R1+R2)/(COS(THETA))
      EN=2.6*Q*(1-(EXP(-(D**2)/((A+(DIST*DIV))**2))))
      REDAT=EXP(-ATMOS*DIST)
      THEPR=ASIN((SIN(THETA))/1.325)
      REDAN=P1*((SIN(THETA-THEPR))**2)/((SIN(THETA+THEPR))**2)
      RED1=P2*((TAN(THETA-THEPR))**2)/((TAN(THETA+THEPR))**2)
      EN=EN*(REDAN+RED1)*REDAT
      IF (EN.GT.PS) THEN
      RL=R1
      R1=(R1+RH)/2.
      GOTO 1
      ELSEIF (EN.LT.(0.98*PS)) THEN
      RH=R1
```

```
      R1=(R1+RL)/2.
      IF (R1.LE.TA) THEN
      R1=TA
      GOTO 5
      ENDIF
      GOTO 1
      ENDIF
      IF (R2.GT.(AINOHD*30.48)) THEN
12    R1=R1+(50.*30.48)
      THETA=BUF+(ATAN((R3+TR)/(R1-TA)))
      RFAR=(R1*(TAN(THETA)))-(R3+TA)
      A2=A1-RFAR
      R2=A2/(TAN(THETA))
      IF (R2.GT.(AINOHD*30.48)) THEN
      GOTO 12
      ENDIF
      ENDIF
5     FA=R1/30.48
      GOTO 3
4     NA=-UNNOHD
      GOTO 40
C NOW COMPARE WITH NEAR BOUNDARY RESTRICTIONS AND OBTAIN HIGHEST
3     IF (FA.GT.NA) THEN
      NA=FA
      ENDIF
C IF THIS IS LESS THEN THE MINIMUM ALTITUDE THE RANGE CONTAINS THEN USE
C THAT MINIMUM
6     IF (NA.LT.SMALL) THEN
      NA=SMALL
      ENDIF
C NOW SET ARRAY VARIABLES EQUAL TO THE COMPUTED VALUES
40    LASER(I,1,J)=NA
      LASER(I,2,J)=RS
      RS=RS-607.61
10    CONTINUE
30    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PRINT(I,INC)
      DIMENSION NEAR(2,10),LASER(10,2,150),FAR(2,10),TAR(3,10),
     1PEAKS(2,10,10),NPEAKS(10),NDATA(10),RUN(10)
      CHARACTER TITLE*20,RUN*20,A*1
      REAL NEAR,FAR,TAR,LASER,PEAKS,NOHD,BUF,INC
      INTEGER NDATA,NPEAKS,FNUM,NADD,I1,NPR,NREC
      COMMON/READ/NEAR,FAR,TAR,PEAKS,LASER,NDATA,NPEAKS,UNNOHD,OPNOHD,
     1BUF/CHAR/TITLE,RUN
      WRITE(*,'(A)')'SUBROUTINE PRINT'
C THIS SUBROUTINE SENDS DATA TO THE PRINTER
      OPEN(6,FILE='PRINTER:')
C SET TAB FOR MAIN TITLE
      WRITE(6,210)
      CLOSE(6)
      OPEN (6,FILE='PRINTER:',FORM='UNFORMATTED')
C SET DOUBLE SIZE MODE
      WRITE(6)14
      WRITE(6)TITLE
C RETURN CARRIAGE
      WRITE(6)10
C SET TO STANDARD LETTER SIZE
      WRITE(6)148
      CLOSE(6)
      OPEN (6,FILE='PRINTER:',FORM='FORMATTED')
C LINE FEED
      WRITE(6,290)
      CLOSE(6)
      OPEN (6,FILE='PRINTER:',FORM='UNFORMATTED')
C SET TO DOUBLE SIZE MODE
      WRITE(6)14
      WRITE(6)RUN(I)
C SET TO STANDARD LETTER SIZE
      WRITE(6)148
      CLOSE(6)
      OPEN(6,FILE='PRINTER:',FORM='FORMATTED')
C LINE FEED
      WRITE(6,215)
      WRITE(6,105)
C SET NOHD'S TO NAUTICAL MILES
      X1=UNNOHD/6076.12
      X2=OPNOHD/6076.12
C SET BUFFER ANGLE TO MILLIRADIANS
      Y=BUF/.001
C WRITE NOHD'S AND BUFFER ANGLE
      IF (X1.EQ.X2) THEN
      WRITE(6,110)X1
      ELSEIF (X1.NE.X2) THEN
      WRITE(6,110)X1
      WRITE(6,112)X2
      ENDIF
      WRITE(6,115)Y
      WRITE(6,105)
C WRITE NEAR BOUNDARY PARAMETERS
      WRITE(6,120)
      WRITE(6,125)NEAR(1,I)
      WRITE(6,130)NEAR(2,I)
      WRITE(6,105)
C WRITE FAR BOUNDARY PARAMETERS
      WRITE(6,135)
```

```
      WRITE(6,125)FAR(1,I)
      WRITE(6,130)FAR(2,I)
      WRITE(6,105)
C IF ONLY ONE TARGET PRESENT
      IF (TAR(3,I).EQ.0) THEN
      WRITE(6,140)TAR(1,I)
C ELSE IF MORE THAN ONE TARGET PRESENT
      ELSEIF (TAR(3,I).GT.0) THEN
      WRITE(6,145)TAR(1,I)
      WRITE(6,150)TAR(2,I)
      WRITE(6,155)TAR(3,I)
      ENDIF
C LINE FEED THEN SET HEADINGS FOR DATA
      WRITE(6,105)
      WRITE(6,220)
      WRITE(6,230)
      WRITE(6,105)
      WRITE(6,160)
      WRITE(6,165)
      WRITE(6,225)
      WRITE(6,170)
C SET INCREMENTS FOR 2 LINES OF DATA
      DA=NDATA(I)/2
      ND=ANINT(DA)
      NINC=ANINT(INC*10)
C SET COUNTER FOR COMMENT LINE
      K=2
      DO 20 J=1,ND,NINC
C SET COUNTER FOR SECOND LINE OF DATA
      I1=J+ND
C SET BOTH RANGES TO NAUTICAL MILES
      R1=LASER(I,2,J)/6076.12
      R2=LASER(I,2,I1)/6076.12
C IF THE FIRST ROW OF DATA DOES NOT HAVE A BUFFER
      IF (LASER(I,1,J).EQ.-UNNOHD) THEN
      K=1
      WRITE (6,300)R1
C ELSEIF THE FIRST ROW DOES HAVE BUFFER
      ELSE
      WRITE (6,310)R1,LASER(I,1,J)
      ENDIF
C IF THE SECOND ROW OF DATA DOES NOT HAVE A BUFFER
      IF (LASER(I,1,I1).EQ.-UNNOHD)THEN
      K=1
      WRITE (6,320)R2
C ELSE IF THE SECOND ROW DOES HAVE BUFFER
      ELSE
      WRITE (6,330)R2,LASER(I,1,I1)
      ENDIF
20    CONTINUE
      WRITE(6,105)
C IF PEAKS ARE PRESENT, WRITE PARAMETERS
      IF (NPEAKS(I).GT.0) THEN
      WRITE (6,180)
      DO 30 J=1,NPEAKS(I)
C SET PEAK DISTANCE TO TGT IN NAUTICAL MILES
      PEAKRA=PEAKS(2,I,J)/6076.12
      WRITE (6,185)PEAKRA,PEAKS(1,I,J)
30    CONTINUE
      ENDIF
      CLOSE(6)
      OPEN(6,FILE='PRINTER:',FORM='UNFORMATTED')
C PROVIDE TWO LINE FEEDS
      WRITE(6)148
      WRITE(6)148
      IF (K.EQ.1) THEN
```

```
      WRITE(6)'**** = NO BUFFER AVAILABLE'
      ENDIF
      WRITE(6)12
      CLOSE(6)
      RETURN
100   FORMAT(5X,A)
105   FORMAT('')
110   FORMAT(2X,'NOHD (UNAIDED VIEWING)=',F8.2,' NM')
112   FORMAT(2X,'NOHD (VIEWING W/OPTICS)=',F8.2,' NM')
115   FORMAT('BUFFER =',F7.2,' M RADIANS')
120   FORMAT('NEAR BOUNDARY ')
125   FORMAT(5X,'ALTITUDE (MSL) =',F8.0,' FT ')
130   FORMAT(4X,'DISTANCE TO TGT =',F8.0,' FT')
135   FORMAT('FAR BOUNDARY')
140   FORMAT('TARGET ALTITUDE      =',F8.0,' FT MSL')
145   FORMAT('NEAR TARGET ALTITUDE =',F8.0,' FT MSL')
150   FORMAT('FAR TARGET ALTITUDE  =',F8.0,' FT MSL')
155   FORMAT('TARGET SEPERATION    =',F8.0,' FT')
160   FORMAT(5X,'DISTANCE',5X,'ALTITUDE',10X,'DISTANCE',5X,'ALTITUDE')
165   FORMAT(6X,'TO TGT',8X,'(FT)',13X,'TO TGT',8X,'(FT)')
170   FORMAT(5X,'--------',5X,'--------',10X,'--------',5X,'--------')
175   FORMAT(1X,F10.2,7X,F7.0,7X,F10.2,6X,F7.0)
180   FORMAT('PEAKS ALONG FLIGHT LINE')
185   FORMAT('DISTANCE TO TGT =',F8.2,' N M',5X,'ALTITUDE =',F8.2,' FT')
190   FORMAT(A)
195   FORMAT('INCREMENTS (0.1,0.5,1.0) ='$)
200   FORMAT(F4.1)
205   FORMAT(I3)
210   FORMAT(20X,$)
215   FORMAT(/)
220   FORMAT(20X,'MINIMUM FLIGHT PROFILE DATA')
225   FORMAT(6X,'(N M)',10X,'MSL',14X,'(N M)',10X,'MSL')
230   FORMAT(20X,'------------------------------')
290   FORMAT(20X,$)
300   FORMAT(1X,F10.2,7X,'*******'$)
310   FORMAT(1X,F10.2,7X,F7.0$)
320   FORMAT(7X,F10.2,6X,'*******')
330   FORMAT(7X,F10.2,6X,F7.0)
      END
```

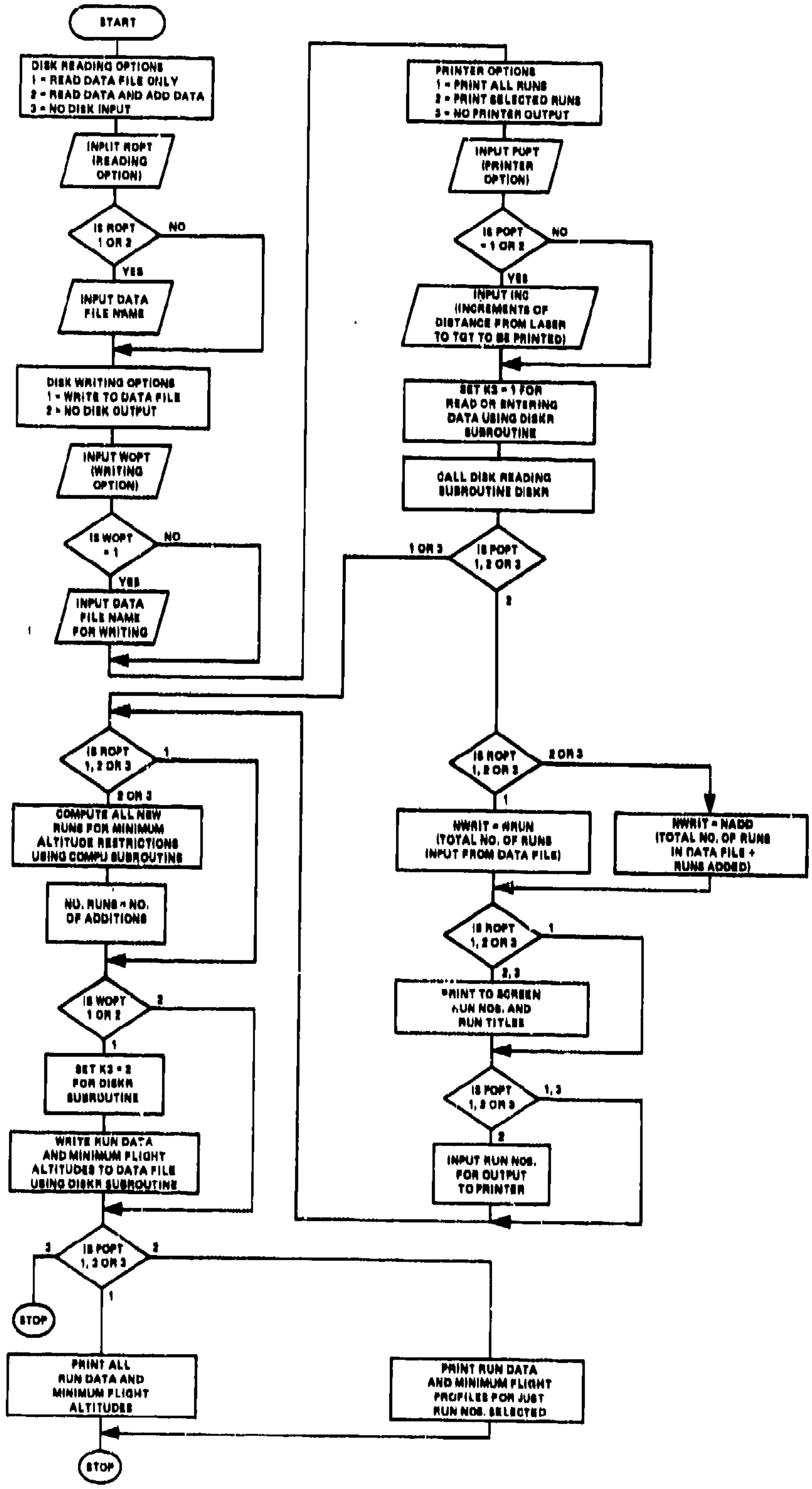
START
DISK READING OPTIONS
1 = READ DATA FILE ONLY
2 = READ DATA AND ADD DATA
3 = NO DISK INPUT
INPUT ROPT (READING OPTION)
IS ROPT 1 OR 2
NO
YES
INPUT DATA FILE NAME
DISK WRITING OPTIONS
1 = WRITE TO DATA FILE
2 = NO DISK OUTPUT
INPUT WOPT (WRITING OPTION)
IS WOPT = 1
INPUT DATA FILE NAME FOR WRITING
PRINTER OPTIONS
1 = PRINT ALL RUNS
2 = PRINT SELECTED RUNS
3 = NO PRINTER OUTPUT
INPUT POPT (PRINTER OPTION)
IS POPT = 1 OR 2
INPUT INC (INCREMENTS OF DISTANCE FROM LASER TO TGT TO BE PRINTED)
SET K3 = 1 FOR READ OR ENTERING DATA USING DISKR SUBROUTINE
CALL DISK READING SUBROUTINE DISKR
IS POPT 1, 2 OR 3
1 OR 3
2
IS ROPT 1, 2 OR 3
2 OR 3
COMPUTE ALL NEW RUNS FOR MINIMUM ALTITUDE RESTRICTIONS USING COMPU SUBROUTINE
NO. RUNS = NO. OF ADDITIONS
IS WOPT 1 OR 2
SET K3 = 2 FOR DISKR SUBROUTINE
WRITE RUN DATA AND MINIMUM FLIGHT ALTITUDES TO DATA FILE USING DISKR SUBROUTINE
NWRIT = NRUN (TOTAL NO. OF RUNS INPUT FROM DATA FILE)
NWRIT = NADD (TOTAL NO. OF RUNS IN DATA FILE + RUNS ADDED)
2, 3
PRINT TO SCREEN RUN NOS. AND RUN TITLES
1, 3
INPUT RUN NOS. FOR OUTPUT TO PRINTER
STOP
PRINT ALL RUN DATA AND MINIMUM FLIGHT ALTITUDES
PRINT RUN DATA AND MINIMUM FLIGHT PROFILES FOR JUST RUN NOS. SELECTED

TABLE OF VARIABLES IN MAIN PROGRAM

ROPT	Read options. The value of ROPT would determine whether the data file was to be read from the disk, whether any runs were to be added, or if it is a new data file.
WOPT	Write option. The value of WOPT will determine if the data is to be written to a data file on the disk.
POPT	Printer options. This will determine whether all runs are to be printed, whether selected runs are to be printed, or no printer output.
FNAMR	Data File name to be read from the disk.
FNAMW	Data File name to which the run data and minimum flight profiles previously computed are to be written.
INC	Increments of ranges (laser to target) in nautical miles that is to be printed on the minimum flight profile table.
DISKR	Subroutine that reads run data and minimum flight profile altitudes from data file FNAMR, prompts for run data for new data files or existing data files, and outputs ALL RUN data and corresponding minimum flight profile to data file FNAMW.
NWRIT	Number of runs that already exists in data file prior to adding any runs.
NRUN	Number of runs input from data file.
NADD	Number of new runs or addition runs to existing runs input from data file.
RUN	Title of each run.
NPRINT	Number of runs for output to the printer.
RPRINT	The run number to be printed.
COMPU	Subroutine for computation of minimum flight altitudes for run data that has not been read from an existing data file.
K3	Selects whether subroutine DISKR is to be used for reading data file or creating a data file

TABLE OF VARIABLES IN SUBROUTINE DISKR

TITLE	Title of data file that resides in either FNAMW or FNAMR. This is the title that will be printed as the main heading on the printer output.
UNNOHD	This is the NOHD for the laser system to be used on the range being evaluated for unaided intrabeam viewing.
OPNOHD	This is the NOHD for this laser system for intrabeam viewing using optical devices.
BUF	One-half the buffer angle for the type of laser to be used.
NRUN	The run number for selected run printout.
RUN	Title of each individual run. This can either be different headings for the laser aircraft, different range parameters or target locations.
NEAR(1,	Altitude of the range boundary closest to the lasing aircraft expressed in feet relative to mean sea level
NEAR(2,	Distance from the target to the range boundary closest to the aircraft.
FAR(1,	Altitude of the range boundary farthest from the lasing aircraft expressed in feet relative to mean sea level
FAR(2,	Distance from the target to the range boundary farthest from the aircraft.
TAR(1,	Target altitude relative to mean sea level for the target closest to the lasing aircraft.
TAR(2,	Target altitude relative to mean sea level for the target farthest from the lasing aircraft
TAR(3,	Target separation. This is zero when only one target is present.
NPEAKS	Number of terrain peaks along the aircraft flight line that are to be considered
PEAKS(1,	Altitude of the peak relative mean sea level
PEAKS(2,	Distance that the peak is from the closest target

TABLE OF VARIABLES IN SUBROUTINE COMPU

RS	Initial range of the aircraft to target for each run. Expressed in feet.
SMALL	Lowest terrain point on range. Aircraft not allowed at less altitude than this point.
BUF	*
AN	Tangent of buffer angle
BN,CN K1,K2,K3,	Near boundary computation variables
NA	Lowest flight altitude that will keep laser beam and buffer on restricted terrain between the boundary closest to the aircraft and the target
UNNOHD K1,K2,K3	Unaided intrabeam viewing NOHD
TEST,X	Used in line of sight over peaks computation
NEAR(1,	*
NEAR(2,	*
FAR(1,	*
FAR(2,	*
TAR(1,	*
TAR(2,	*
TAR(3,	*
PEAKS(1,	*
PEAKS(2,	*
'NPEAKS	*
RFAK,K1,K2 BF,K3,CF	Variables used in far boundary calculations
FA	Minimum altitude above which laser beam and its buffer will be constrained within controlled terrain. If this is higher than the near boundary minimum altitude, than FA will be the minimum altitude.
R3,A1,R1, RH,RL,TR TA	Variables of all distances and NOHD's expressed in CM

*See table of variables in subroutine DISKR for description.

THETA, A2 R2,	Variables used in reflection calculations
DIST	Altitudes of viewing aircraft and lasing aircraft
REDAT	Reduction of energy due to atmospheric attenuation
REDAN, RED1	Reduction of energy for horizontal and vertical reflection coefficients, respectively
EN	Energy at viewing aircraft
AINOHD	Single pulse NOHD for aircraft crew unaided intrabeam viewing
LASER(,1	Minimum altitude of lasing aircraft where laser beam will be constrained within either controlled range boundaries or restricted airspace
LASER(,2	Corresponding range to target of lasing aircraft for which laser-(,1 applies

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Naval Electronics Systems Command
ATTN: 01K
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